viii. Standard Aperture CQS Assemblies

The CQS assemblies consist of various combinations (over 80 types) of quadrupole, sextupole and corrector elements assembled together into a common cold mass containment and vacuum vessel [MU95a]. The weight of a CQS assembly is typically 948 kg. The quadrupole and sextupole elements were manufactured industrially, the corrector elements were manufactured in-house at Brookhaven. These elements, along with numerous other components, make up the single complete unit for the RHIC ring. Components included are recoolers for the main helium distribution circuit, beam position monitors, power leads for the included corrector magnets [SH93a], and instrumentation and heater leads with the leads exiting the cryostat locally. Special tooling to control the positions and rotations of the elements during assembly, and instrumentation to measure these parameters afterwards [GO93a, TR95a, JA97a], was developed. A special shell-welding technique was developed to remove any excessive residual twist in these assemblies as well as in the larger 130 mm assemblies [CO97a]. Because of their ubiquitous location around the machine, a rigorous analysis of bellows' strength and operational range was performed [SH90a, SH91a]. This analysis describes the bellows required for interconnecting these devices to their neighbors in the rings. Figure 8-1 shows the magnets of a CQS unit on the assembly bench.

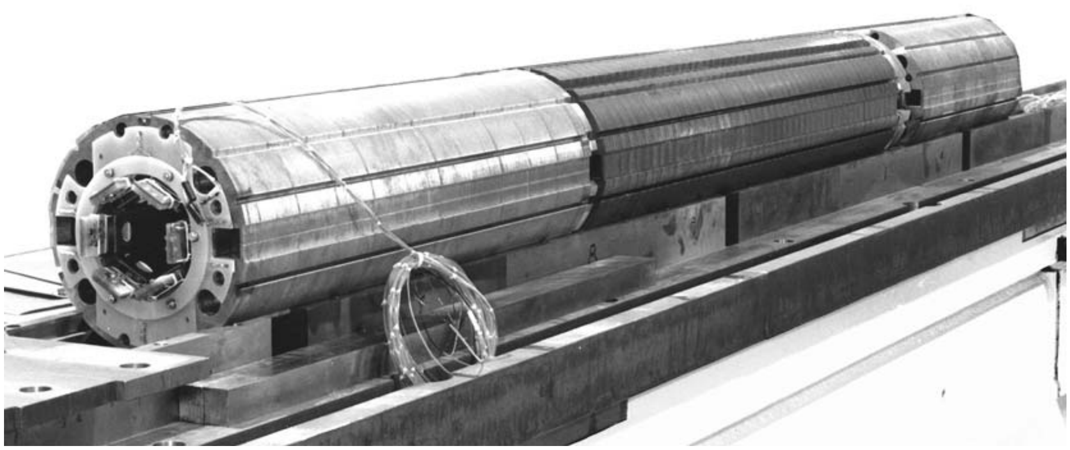

Fig. 8-1. The magnets of a CQS unit on the assembly bench. In the foreground is a sextupole cold mass, followed by quadrupole and corrector cold masses.

The magnetic centers of the CQS elements were measured by two unusual methods: colloidal cell and harmonic antenna. A number of quadrupoles were measured by shining polarized light through a cylindrical glass cell containing a colloidal suspension of iron filings [TR95a]. In a sufficiently strong field, the iron filings lined up along field lines enough to rotate the plane of polarization of the light. The light was viewed through a second filter, which was rotated 90° with respect to the first. The transmitted light produced field patterns that were accurate to ± 50 μm. Because of limitations in this technique, a more versatile device, the harmonic antenna, was developed. With this device, the field center was measured on all three elements of the CQS. The harmonic antenna is a stationary coil, 23 cm long, that senses the fields produced by AC currents in the range 10 – 20 Hz. The coil also has crossed wires mounted precisely across its ends, allowing its position to be surveyed relative to external fiducials to within 0.025 mm. The field center relative to the coil is also determined within 0.025 mm, even in measurements at room temperature [JA97a].

The installation procedure for the CQS called for the centers of the quadrupole and sextupole to be installed on the central beam orbit, so the measurements were analyzed to report the "corrector offset," the distance between the center of the corrector and the beam orbit. After a learning curve, rms corrector offsets of 0.5 mm were achieved [WE96].

To establish the warm-cold correlations, the first 30 CQS units plus 18 of the remaining units were cold tested. For CQS units, the main focus of the correlation is the field angles. For both the quadrupole and the sextupole, the mean warm-cold difference in field angles was –0.2 mrad, with an rms of 0.4 mrad (Fig. 8-2). For dipole correctors, the mean field angle difference was –0.3 mrad with an rms of 0.5 mrad. The centers of the magnetic field were measured warm and cold in one CQS (Fig. 8-3). The field center was measured at three axial positions in the quadrupole and two in the sextupole. The change in vertical position, about 1.75 mm, agrees with the change expected due to thermal contraction. The change in horizontal position is about 0.25 mm.

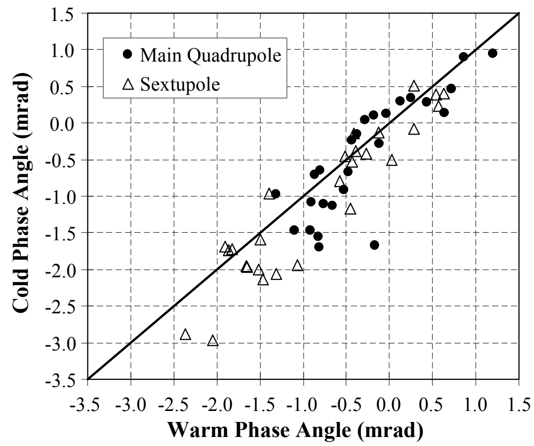

Fig. 8-2. Warm-cold correlations of CQS field angles.

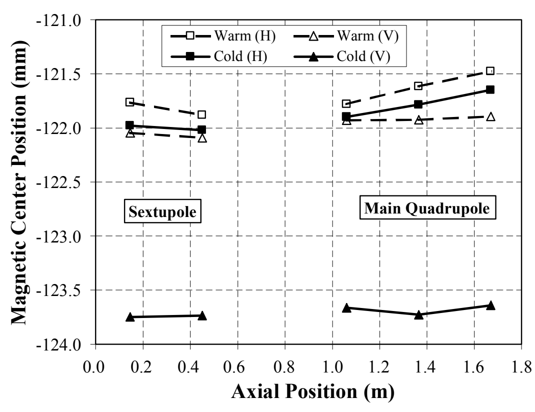

Fig. 8-3. Correlation between warm and cold centers in a CQS assembly.

CQS Cryostat

The cryostat is the structure which must make the transition from the 4 K environment of the magnet cold mass to ambient temperature; the corrector, quadrupole and sextupole (CQS) units are mounted in one common cryostat. In addition, five 50 W "recoolers" per sextant are located under the CQS assembly in the space between the support posts in the 4 K environment. The CQS cryostat design parameters are summarized in Table 8-1. The major components comprising the cryostat are the 6.4 mm thick carbon steel (ASTM A53) vacuum vessel of 610 mm outer diameter, the aluminum heat shield (1100-H14) maintained at nominal 55 K, blankets of multilayer aluminized Mylar thermal insulation, the various cryogenic headers, and the post-type supports which carry the loads generated by the magnet cold masses to the ground. The superinsulation blankets use alternating layers of reflectors (0.25 mil non-crinkled Mylar, aluminized on two sides) and spacers (6 mil REEMAY 2006).

The support posts are the same as used in the arc dipoles. The standard arc CQS assembly is supported by two posts, one located at the sextupole and the other at the corrector. They were precision molded as tubes with flanges from a glass-filled plastic material under the name Ultem 2100. The tubes are in two parts, bolted together at the heat shield. The cold mass is attached to cradles which rest atop each post; the cradles are machined from stainless steel castings. Both cradles are free to move during cooldown; stops on the posts are spaced such that each post is deflected 0.5 mm after cooldown.

The cryostat must accurately position the magnet cold masses to a given point in the accelerator lattice, while at the same time minimizing the refrigeration load. The legs of the vacuum chamber are carbon steel castings. The surfaces of these legs are used to provide the exterior survey fiducial references; survey fixtures will translate the positional information provided by the reference features to a location outside the vacuum tank.

Table 8-1. CQS Cryostat Parameters

Vacuum vessel, outer diameter	(24 in.) 610	mm
Vacuum tank, wall thickness	(0.25 in.) 6.4	mm
Heat shield, outer diameter	(21 in.) 533	mm
Heat shield, wall thickness, upper section	(0.090 in.) 2.29	mm
Heat shield, wall thickness, lower section	(0.125 in) 3.18	mm
Recooler supply header, inner diameter	(2.709 in.) 68.8	mm
Helium return header, inner diameter	(2.709 in.) 68.8	mm
Utility header, inner diameter	(2.709 in.) 68.8	mm
Shield cooling pipe, inner diameter	(2.157 in.) 54.8	mm
Number of supports	2	
Support spacing	(74 in.) 1.88	m
Post, inner diameter	(8.38 in.) 212.8	mm
Post, wall thickness	(0.189 in.) 4.8	mm
Heat leak per leg at 4.5 K	0.1	W
Heat leak per leg at 55 K	1.0	W
Superinsulation layers, cold mass only	17 Reflector, 32 Spacer	
Superinsulation layers, cold mass plus piping	38 Reflector, 53 Spacer	
Superinsulation layers, shield	62 Reflector, 62 Spacer	

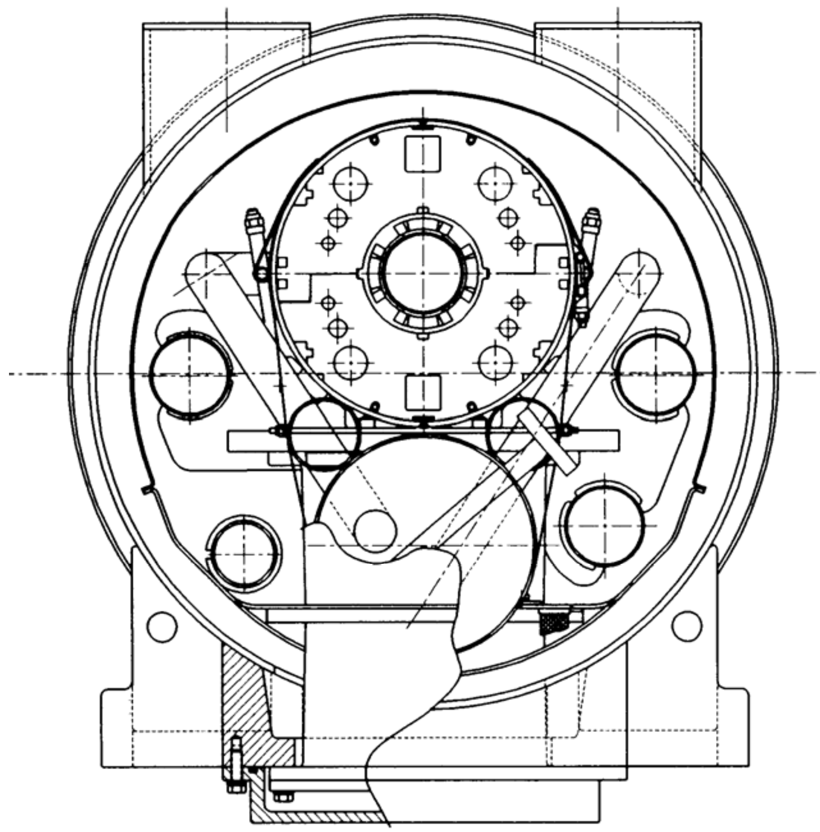

Fig. 8-3. Quadrupole cryostat cross-section, showing recooler.